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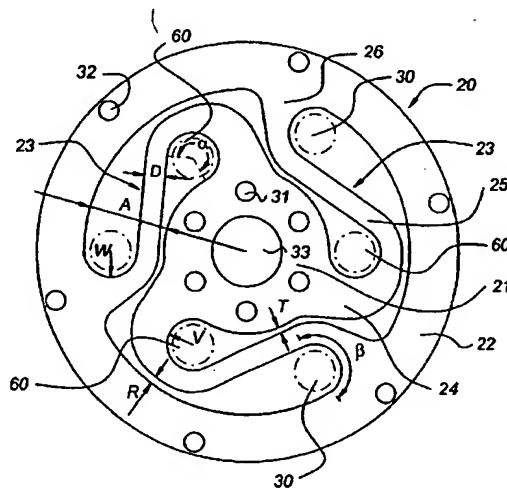
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[Continued on next page]

(54) Title: LEAF SPRING, AND ELECTROMAGNETIC ACTUATOR PROVIDED WITH A LEAF SPRING



(57) Abstract: The invention relates to a leaf spring for an electromagnetic actuator and to such an electromagnetic actuator. The leaf spring is formed as a whole from a disc of plate-shaped, resilient material. The leaf spring comprises a central fastening part, an outer fastening part extending therearound and at least two leaf spring arms extending between the central and outer fastening part. Viewed from the central fastening part, the leaf spring arms (23) have a first zone (24) originating from the central fastening part (21), in which they extend as far as the outer part (22) but for a first clearance (R). The first zone (24) is followed by a second zone (25) in which, without contacting the outer fastening part (22) and proceeding in tangential direction, they bend back as far as the central fastening part (21) but for a second clearance (T). A third zone (26) follows the second zone (25), in which the spring leaf arms (23) extend towards the outer fastening part (22) to merge therein.

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**Title: Leaf spring, and electromagnetic actuator provided with a leaf spring.**

The present invention relates to a leaf spring, such as, in particular, for an electromagnetic actuator,

wherein the leaf spring as a whole is formed from a disc of plate-shaped, resilient material, and

5       wherein the leaf spring comprises:

- a central fastening part;
- an outer fastening part extending at a distance from the central fastening part around the fastening part; and
- at least two leaf spring arms connecting the central and outer fastening part.

10       Such a leaf spring is known from the German Offenlegungsschrift DE 198,23,716. The leaf spring known therefrom, shown in particular in Fig. 3, has three leaf spring arms extending in a spiral shape from the centre to an outer ring. The drawback of this known leaf spring is that at the transition of 15       the leaf spring arms into, on the one side, the centre and, on the other side, the circumferential ring, during use, large tension peaks will occur and that in that transition area, this known leaf spring will be susceptible to fatigue tears as a consequence of the rather sharp bends which are made by the side edges of the leaf spring arms.

20       The present invention intends to provide an improved leaf spring of the type mentioned in the opening paragraph, which, with a relatively compact construction, allows leaf spring arms with a relatively great length, which has a long life span, and in particular, which has a limited susceptibility to formation of fatigue tears under the influence of internal material stresses 25       occurring during use. The object referred to can be achieved in two ways, starting from the same, common basic principle. This common basic principle is that one allows the leaf spring arm, proceeding from the one fastening part

to the other fastening part, to, first, cross as far as that other fastening part but for a clearance, to, then, have the leaf spring arm, without it coming into contact with the other fastening part and proceeding in tangential direction, bend back to the one fastening part, but for a second clearance. Thus, upon

5 departure from the one fastening part, a wide bend, in particular a wide inner bend is provided instead of a sharp inner bend as is the case in DE-19823716 – which leads to, on the one hand, more limited internal material stresses during use and, on the other hand, to a relatively long leaf spring arm.

According to a further, special embodiment, then, from the point where the

10 leaf spring arm is bent back to the one fastening part but for a clearance, the leaf spring arm will cross towards the other fastening part to merge into that other fastening part. The advantage here is that also at the transition of the leaf spring arm into the other fastening part a wide bend is possible, which, again, is of advantage both with regard to the material stresses occurring

15 internally in the leaf spring arm during use and with regard to the thus obtained relatively longer length of the leaf spring arm. Starting from the central fastening point, this can be formulated following a first way as represented in claim 1 and claim 2 dependent thereon. Starting from the outer fastening part, this can be formulated following the second way as represented

20 in claim 3 and claim 4 depending thereon.

According to a special embodiment, it is advantageous when the first or third zone has a radial main extending direction. What is meant by a radial main extending direction is that, when the extending direction of the first or third zone is divided into a radial and tangential component, the radial

25 component is the larger component and is preferably at least 40% greater than the tangential component.

According to a further advantageous embodiment, it is advantageous when the size of the first and/or the second clearance in radial direction is less than 25%, preferably less than 15%, such as, approximately 10%, of the radial

30 distance from the central fastening part to the outer fastening part. Further,

the size of the first and/or second clearance will preferably be greater than approximately 2.5% of the radial distance from the central fastening part to the outer fastening part. With the size of the first and/or second clearance being such, one can, on the one hand, have a relatively wide transition bend to

5 the second zone and, on the other hand, one can thus obtain a relatively long leaf spring arm. The minimum size of the clearance is of importance to prevent contact between the leaf spring arm via the respective clearance when, during use, forces act on the central and outer fastening part which have the tendency to, locally, cause the two fastening parts to move towards each other.

10 According to a different advantageous embodiment, all this can be expressed in a more absolute way and it is preferred, then, that the size of the first and/or second clearance in radial direction be less than 5 mm, such as approximately 3.5 mm, and preferably at least 0.5 mm, such as 1 mm.

With a view to reducing, as much as possible, internal material stresses

15 which occur during use in particular at the inside bend of the transition of the first zone to the second zone, it is preferred, according to the invention, that the side of the first zone proximal to the second zone extends with a first radius of curvature (V) which, in approximation or not so, meets the following relation:

20

$$V = (A - R - D)/2$$

with

25 A = the radial distance between the central and outer fastening part measured through the centre of the first radius of curvature;

R = the radial size of the first clearance;

D = the width of the second zone.

Thus, with A, R and D given, a maximum radius of curvature is obtained

30 which can remain constant throughout the configuration of the inside bend.

According to a further special embodiment, the first radius of curvature (V) extends over an angular range larger than 200°, preferably a range of 215° to 245°, such as, approximately 230°. Thus, without a change in radius of curvature, a uniform transition in a zone of the leaf spring arm bending back 5 towards the central fastening part becomes possible.

In a corresponding manner it is preferred, according to the invention, when the side of the third zone proximal to the second zone proceeds with a second radius of curvature (W), which, in approximation or not so, meets the following relation:

10

$$W = (A - T - D)/2$$

with:

15     A = the radial distance between the central and outer fastening part measured through the centre of the second radius of curvature;  
T = the radial size of the second clearance;  
D = the width of the second zone.

20     According to the invention, it is of special advantage here when the second radius of curvature (W) extends over an angular range of approximately 180°. Thus, in particular, it becomes possible to obtain a straight second zone, bending back, of the leaf spring arm.

According to a further embodiment, it is preferred when the leaf spring 25 arms are aligned and are evenly arranged around the central fastening part. Thus, during use, a uniform distribution of spring forces is achieved.

According to a further special embodiment, it is preferred when the leaf spring comprises three, four, five or six spring arms. The leaf spring with three or four spring arms will be most preferred. Three or four spring arm still allow 30 a good, relatively even distribution of spring forces over the circumference of

the central fastening zone while, on the other hand, they still allow relatively long leaf spring arms.

With a view to avoiding high internal material stresses during use, in particular in the transition areas from the first to the second zone and from 5 the second to the third zone, and in the transition areas of the central fastening part to the first zone of the outer fastening part to the third zone, it is preferred according to the invention when, viewed transversely to the extending direction, the width of the leaf spring arm in the first and/or second zone is greater than or equal to the width of the second zone, viewed 10 transversely to the extending direction.

According to a further aspect, the invention relates to an electromagnetic actuator, comprising a first actuator part and a second actuator part, which are connected to each other by means of suspension means allowing mutual movement, characterized in that the suspension 15 means comprise one or more leaf springs according to the invention.

According to a further special embodiment, the electromagnetic actuator according to the invention has further suspension means in the form of one or more coil springs which extend perpendicularly to at least one of the leaf springs through that leaf spring. The fact is that thus, while maintaining a 20 compact construction, it becomes possible to support the first and second actuator part on each other, not only via the leaf springs, but also via coil springs.

In the following, the present invention will be further elucidated with reference to an embodiment schematically represented in the drawing. In the 25 drawing:

Fig. 1 shows a schematic representation of an electromagnetic actuator according to the invention in cross-sectional, partial front view;

Fig. 2 shows a top plan view of a leaf spring according to the invention; and

Fig. 3 shows a detail in longitudinal section of a view in part of a variant of the electromagnetic actuator according to Fig. 1.

Fig. 1 shows, in cross-sectional partial front view an actuator 1 according to the invention. The actuator 1 consists of a fixed part 2 and a moving part 15 received therein. The moving part 15 can optionally be connected to the outside world with a first rod 12 and, optionally, a second rod 13. With for instance a so-called "shaker", the rods 12, 13 can be completely omitted. A vibration, for instance from the outside, can act on rod 12 and/or 13, which vibration has to be actively damped by the actuator 1. It is also conceivable to impose a vibration departing from the actuator 1, via the rods 12 and/or 13 onto the outside world. The fixed part 2 can be connected to the outside world via flange 8. It is noted that, without exceeding the scope of the invention as laid down in the claims, the fixed part 2 can also function as a moving part, while the moving part 15 can also function as fixed part. All this will be dependent on the manner in which the actuator 1 is connected to the outside world.

The fixed part 2 consists of a core 3 of non-magnetic material having thereon three coils 4, 5 and 6, and, around these coils 4, 5 and 6, a shell 7. As to their magnetic orientation, the electromagnetic coils 4 and 6 are oriented identically and the coil 5 is orientated in precisely the opposite way. Such a configuration of coils can be achieved with a suitable connection to an electric source. However, this orientation can also be achieved by winding the coils 4, 5 and 6 from one and the same wire and by making the winding direction of the coils 4 and 6 identical and the winding direction of coil 5 precisely opposite.

The wire from which the coils 4, 5 6 have been wound will be a metal wire, preferably a copper wire or aluminum wire.

The shell 7 is manufactured from a ferromagnetic material, for instance a suitable type of steel.

The core 3 is of a cylindrical hollow design. Optionally, the core 3 can have an oval, square, rectangular and differently shaped hollow cross section.

The moving part 15 of the actuator 1 is received in the hollow core 3. This moving part 15 consists of two permanent magnets, 9, the upper one in Fig. 1, and 10, the lower one in Fig. 1. The lower permanent magnet 10 has its South pole turned downwards and North pole turned upwards and the upper 5 permanent magnet 9 has its South pole turned upwards and North pole turned downwards. It is of primary importance that the permanent magnet 9 and 10 have their equivalent poles turned towards each other, although also configurations are conceivable where the non-equivalent poles are turned towards each other. Between the magnets 9 and 10 there is a disc of 10 ferromagnetic material.

By means of a lower spring 20 and an upper spring 20, the moving part 15 of the actuator 1 is suspended in the core 3. The springs 20 are leaf springs. On the one side, the leaf springs 20 are fixedly connected to the rods 13 and 12, respectively, and on the other side to the core 3. At the upper side and the 15 lower side, the moving part 15 of the actuator 1 is further provided with a ferromagnetic disc 16 and 17.

The distance 'd' is the distance from the moving part 15 of the actuator to the ferromagnetic shell 7. The thicknesses of the outer ferromagnetic discs 16 and 17 are mutually identical and indicated with 'h'. The thickness of the 20 middle ferromagnetic disc 11 is indicated with the letter 'f'. An efficient actuator is obtained when the following relation applies:

$$f = 2h + 0.5d.$$

25 Presently referring to Fig. 2, the leaf spring 20 according to the invention as used with the actuator from Fig. 1 will be further described.

In the exemplary embodiment represented in Fig. 2, the leaf spring 20 is essentially of circular appearance. However, it is noted that, although a circular appearance is preferred, the leaf spring according to the invention can 30 also have an elliptic or oval shape.

The leaf spring 20 is essentially built up from three parts. A central fastening part 21 of essentially annular appearance. The central fastening part 21 is provided with a central passage 33 through which the rod 12 or 13 can extend. Further, the central fastening part 21 is provided with bolt passages 5 31 to enable the leaf spring 20 to be screwed to the moving actuator part 15 by means of bolts, as is schematically represented in Fig. 1 and 3 with reference numeral 34.

Further, the leaf spring 20 has an outer fastening part 22 which is also ring-shaped, elliptical or oval. The outer fastening part 22 is provided with bolt 10 passages 32 for, as is schematically indicated in Figs. 1 and 3 with 35, securing the leaf spring 20 to the fixed actuator part 2 by means of bolts.

Between the central fastening part 21 and the outer fastening part 22, leaf spring arms 23 extend. Each leaf spring arm 23 is built up from a first zone 24 originating from the central fastening part 21, which merges into a 15 second zone 25 which merges into a third zone 26, which originates from the outer fastening part 22.

As can be seen in Fig. 2, the first zone 24 extends from the central fastening part 21 initially in radial direction to a point near to the outer fastening part 22 while leaving a first clearance R clear. Here, the first zone 21 20 merges into a second zone 25 which extends roughly – not exactly – in tangential direction then, to bend back to the central fastening part as far as a point at a distance the size of a second clearance T, then to merge into a third zone 26 which essentially extends radially towards the outer fastening part 22. Of special importance with regard to the internal material stresses are the 25 inside bend at the transition from the first zone 24 to the second zone 25 and the inside bend at the transition from the second zone 25 to the third zone 26.

The inside bend, from the first zone 24 to the second zone 25, measured from the central fastening part 21, extends over an angular range  $\alpha$  of approximately  $230^\circ$  and, according to the invention, preferably has a constant 30 radius of curvature. With a given transversely measured width D of the second

zone, radial distance A between the central fastening part 21 and outer fastening part 22 and first clearance R, this radius of curvature V can be defined as:

5  $V = (A - D - R)/2$

In a corresponding manner, the geometry of the inside bends at the transition of the second to the third zone and to the outer fastening part 22 can be defined. Preferably, this inside bend will extend over an angular range  $\beta$  of 10 approximately 180° and, given the fixed transverse width D of the second zone, radial intermediate distance A between the central fastening part 21 and the outer fastening part 22 and dimension of the clearance T can be defined as:

$W = (A - D - T)/2$

15

As a result of the wide inside bends at the transition of, on the one side, the first zone to the second zone and, on the other side, the second zone to the third zone, it becomes possible, while maintaining a compact construction, to use coil springs for supporting the fixed actuator part on the moving actuator 20 part. The fact is that the coil springs 30 can extend transversely to the leaf spring 20 through that leaf spring, more preferably so at the location of the inside bend from the second zone to the third zone but, optionally also, or instead, at the location of the inside bend from the first zone to the second zone (coil springs 60). All this is schematically indicated in particular in Fig. 3. For 25 closing the leaf springs 30, a closing end 36 is to be provided on the core 3, which can be attached by the same bolts 35 with which the leaf spring 20 has been attached and which can support the springs 30 on the inside. Such a closing end 36 with springs 30 can be provided at an axial end or at both axial ends of the actuator.

Referring to, in particular, Figs. 1 and 3, it is noted that an actuator according to the invention, instead of, each time, having the one leaf spring 20 at the bottom side and the top side, can also be provided at that bottom side and top side with a number of superposed leaf springs, which will preferably 5 be kept at some mutual distance by a respective distancing element to prevent mutual frictional effects.

The superposed leaf springs can also be mutually connected by means of a (visco) elastic layer so that a laminate is formed of one or more layers of leaf springs and elastic material. The soft elastic intermediate layers "follow" the 10 deformation of the leaf springs and thus, in an effective manner, damp possible resonances in the leaf springs.

In order that the leaf springs do not form part or will not form part of the magnetic circuit of the actuator, at least will not influence the circuit, it is preferred to make the leaf spring of a non-magnetic and non-magnetizable 15 material, such as phosphor bronze or beryllium copper.

Claims

1. A leaf spring (20), such as, in particular, for an electromagnetic actuator (1), wherein the leaf spring (20) as a whole is formed from a disc of plate-shaped, resilient material, and  
wherein the leaf spring (20) comprises:
  - 5 - a central fastening part (21);
  - an outer fastening part (22) extending at a distance from the central fastening part (21) around the fastening part (21); and
  - at least two leaf spring arms (23) connecting the central (21) and outer (22) fastening part;
- 10 characterized in that,  
viewed from the central fastening part (21), the leaf spring arms (23) have a first zone (24) originating from the central fastening part (21), in which they extend as far as the outer fastening part (22) but for a first clearance (R), and a second zone (25) following the first zone (24) in which, without contacting the outer fastening part (22) and proceeding in tangential direction, they bend back as far as the central fastening part (21) but for a second clearance (T).
- 15 2. A leaf spring (20) according to claim 1, characterized in that,  
viewed from the second zone (25), a second zone (25) is followed by a third zone (26) in which the leaf spring arms (23) extend towards the outer fastening part (22) to merge into the outer fastening part (22).
- 20 3. A leaf spring (20), such as, in particular, for an electromagnetic actuator (1), wherein the leaf spring (20) as a whole is formed from a disc of plate-shaped, resilient material, and  
wherein the leaf spring (20) comprises:
  - 25 - a central fastening part (21);
  - an outer fastening part (22) extending at a distance from the central fastening part (21) around the central fastening part (21); and

at least two leaf spring arms (23) connecting the central (21) and outer (22) fastening part; characterized in that, viewed from the outer fastening part (22), the leaf spring arms (23) have a third zone (26) originating from the outer fastening part (22), in which they extend as far as the central fastening part (21) but for a second clearance (T), and have a second zone (25) following the third zone (26), in which, without contacting the central fastening part (21), proceeding in tangential direction, they bend back as far as the outer fastening part (22) but for a first clearance (R).

4. A leaf spring (20) according to claim 3, characterized in that viewed from the second zone (25), a second zone (25) is followed by a first zone (24) in which the leaf spring arms (23) proceed to the central fastening part (21) to merge into the central fastening part (21).

15 5. A leaf spring (20) according to any one of the preceding claims, characterized in that the first (24) or third (26) zone has a radial main extending direction.

6. A leaf spring according to any one of the preceding claims, characterized in that the size of the first (R) and/or second (T) clearance in 20 radial direction is less than 25%, preferably less than 15%, such as, approximately 10%, of the radial distance (A) from the central fastening part (21) to the outer fastening part (22).

25 7. A leaf spring (20) according to any one of the preceding claims, characterized in that the size of the first (R) and/or second (T) clearance in radial direction is less than 5 mm, such as approximately 3.5 mm, and preferably at least 0.5 mm, such as 1 mm.

8. A leaf spring (20) according to any one of claims 1, 2, 4 – 7, characterized in that the side of the first zone (24) proximal to the second zone (25) proceeds with a first radius of curvature (V) to which, in 30 approximation, applies:

$$V = (A - R - D)/2$$

with:

5

A = the radial distance between the central and outer fastening part measured through the centre of the first radius of curvature;  
R = the radial size of the first clearance;  
D = the width of the second zone.

10 9. A leaf spring (20) according to claim 8, characterized in that the first radius of curvature (V) extends over an angular range ( $\alpha$ ) greater than 200° and preferably in the range of 215° to 245°, and is, for instance, approximately 230°.

10. A leaf spring (20) according to any one of claims 2 – 9,

15 characterized in that the side of the third zone (26) proximal to the second zone (25) proceeds with a second radius of curvature (W), to which, in approximation, applies:

$$W = (A - T - D)/2$$

20

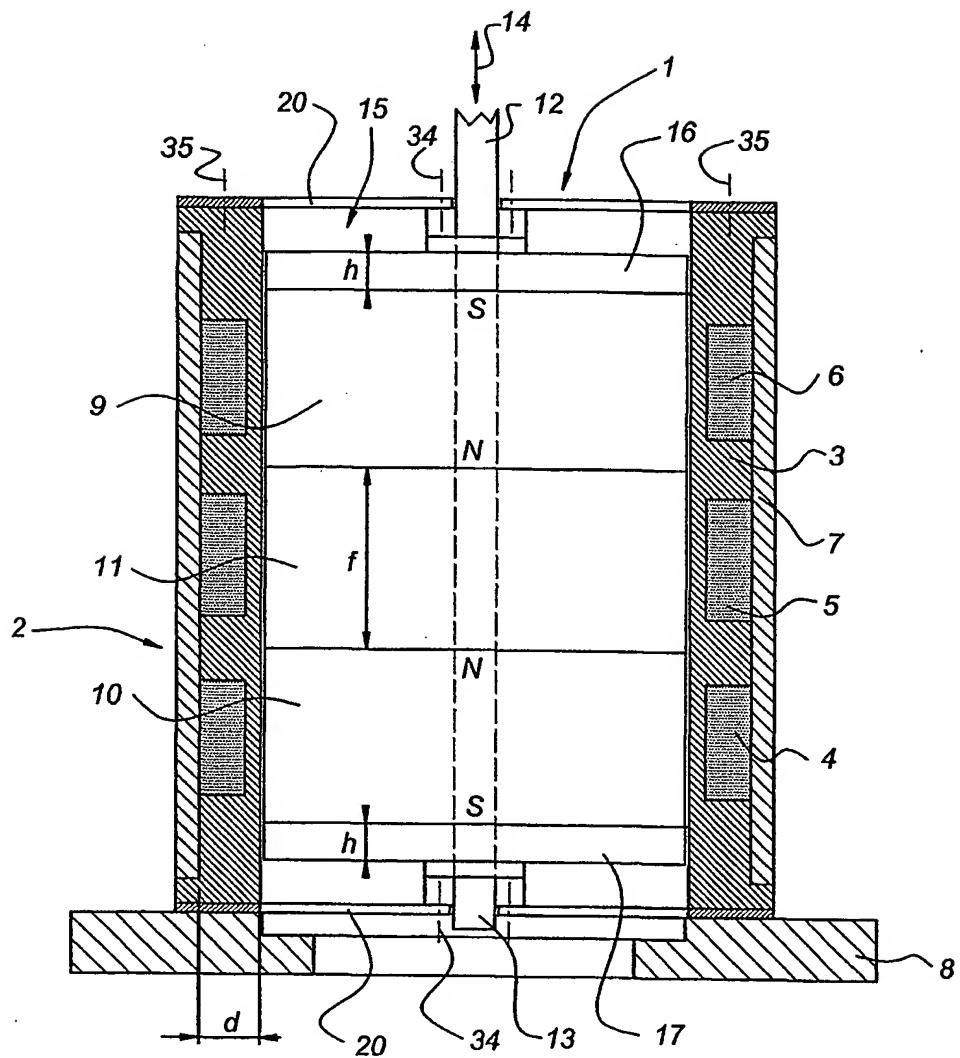
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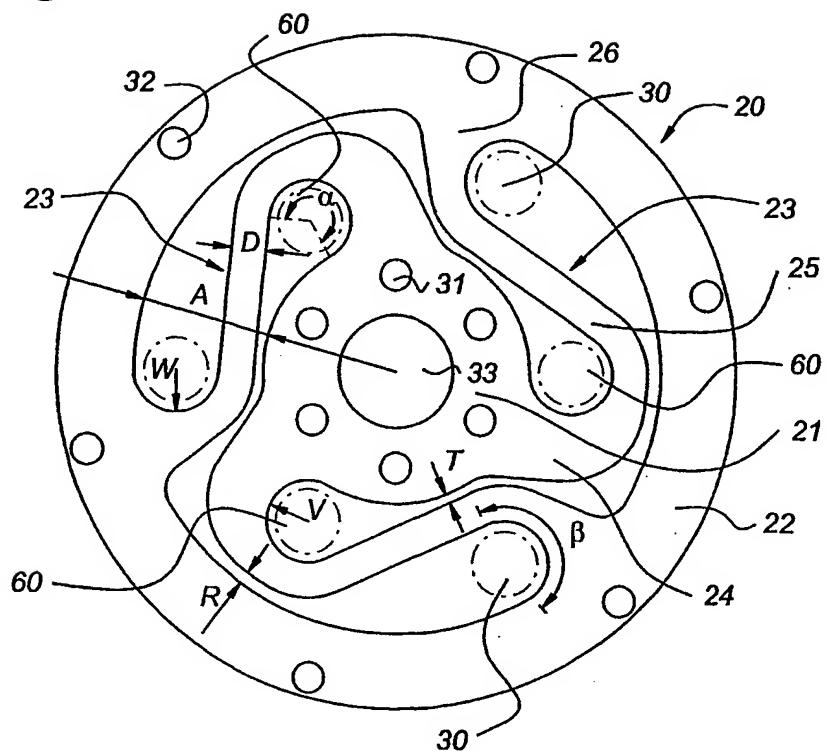
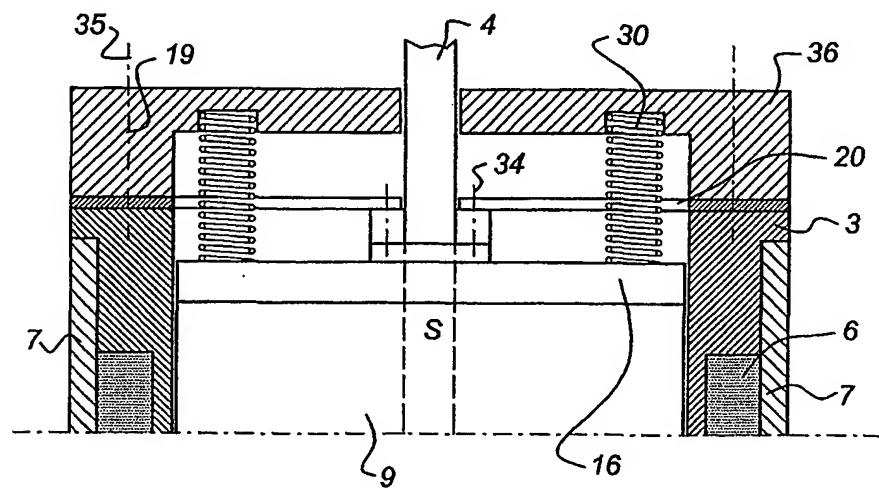
A = the radial distance between the central and outer fastening part measured through the centre of the second radius of curvature;  
25 T = the radial size of the second clearance;  
D = the width of the second zone.

11. A leaf spring (20) according to claim 10, characterized in that the second radius of curvature (W) extends over an angular range ( $\beta$ ) of approximately 180°.

12. A leaf spring (20) according to any one of the preceding claims, characterized in that the spring arms (23) are aligned and are arranged to be evenly distributed around the central fastening part (21).
13. A leaf spring (20) according to any one of the preceding claims, 5 characterized in that it comprises three, four, five or six spring arms (23).
14. A leaf spring (20) according to any one of the preceding claims, characterized in that, viewed transversely to the extending direction, the width of the leaf spring arm (23) in the first (24) and/or third (26) zone is greater than or equal to the width of the second zone (25) viewed transversely 10 to the extending direction.
15. A leaf spring (20) according to any one of the preceding claims, characterized in that the leaf spring is made from a non-magnetic and non-magnetizable material, in particular a metal, such as phosphor bronze.
16. An electromagnetic actuator (1), comprising a first actuator part (2) 15 and a second actuator part (15) which are connected to each other by means of suspension means (20, 30) allowing mutual movement, characterized in that the suspension means comprise one or more leaf springs (20) according to any one of claims 1 – 14.
17. An electromagnetic actuator (1) according to claim 16, 20 characterized in that the suspension means further comprise one or more coil springs (30) extending perpendicularly to at least one of the leaf springs (20) through that leaf spring (20).

Fig. 1



*Fig 2**Fig 3*

## INTERNATIONAL SEARCH REPORT

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NL 02/00113A. CLASSIFICATION OF SUBJECT MATTER  
IPC 7 F16F1/32

According to International Patent Classification (IPC) or to both national classification and IPC

## B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)  
IPC 7 F16F G01V H04R H01F

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal

## C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	DE 70 15 469 U (MASCHINENFABRIK STROMAG) 3 August 1972 (1972-08-03) claim 1; figure	1-4
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 Further documents are listed in the continuation of box C. Patent family members are listed in annex.

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Name and mailing address of the ISA

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## INTERNATIONAL SEARCH REPORT

International Application No  
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## C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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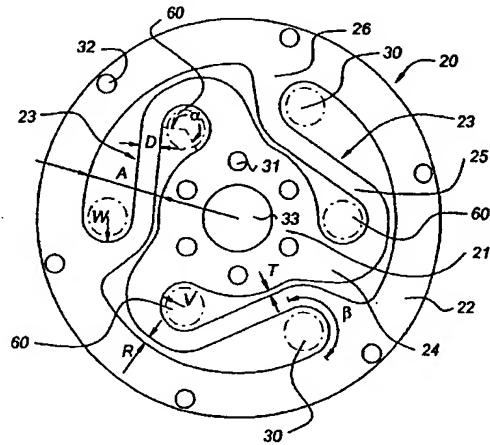
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